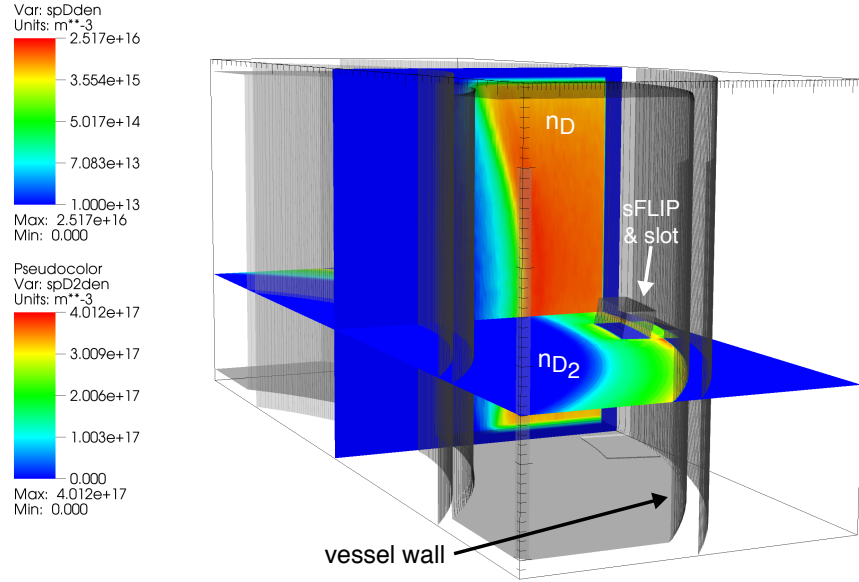# DEGAS 2

Slices through the three-dimensional atomic (vertical) and molecular (horizontal) deuterium profiles in a simulation of data from the NSTX Edge Neutral Density Diagnostic.

Neutral atoms and molecules in fusion plasmas are of interest for multiple reasons. First, neutral particles are produced via the interactions of the plasma as it flows along open field lines to surrounding material surfaces. Unconfined by the magnetic field, the atoms and molecules provide a channel for heat transport across the field lines and also serve as a source of plasma particles via ionization. Second, atoms that penetrate well past the last closed flux surface can charge exchange with plasma ions to generate high energy neutrals that can strike the vacuum vessel wall, sputtering impurities into the plasma and possibly damaging the wall. Third, the most common means of fueling plasmas is with an external puff of gas. Finally, the light emitted by the neutral atoms and molecules in all of the above processes can be monitored and used as the basis for diagnostics.

Kinetic models of neutral particle transport are based on the Boltzmann equation. For the simple case of a single "background" species and a single binary collision process, this is:

$$
\begin{aligned}
\frac{\partial f(\mathbf{r}, \mathbf{v}, t)}{\partial t} \; &+ \; \mathbf{v} \cdot \nabla_{\mathbf{r}} f(\mathbf{r}, \mathbf{v}, t) \\
&= \; \int d\mathbf{v}' \, d\mathbf{V}' \, d\mathbf{V} \sigma(\mathbf{v}', \mathbf{V}'; \mathbf{v}, \mathbf{V}) |\mathbf{v}' - \mathbf{V}'| f(\mathbf{v}') f_b(\mathbf{V}') \\
&- \; \int d\mathbf{v}' \, d\mathbf{V}' \, d\mathbf{V} \sigma(\mathbf{v}, \mathbf{V}; \mathbf{v}', \mathbf{V}') |\mathbf{v} - \mathbf{V}| f(\mathbf{v}) f_b(\mathbf{V}),
\end{aligned}
$$

where $f(\mathbf{r}, \mathbf{v}, t)$ and $f_b(\mathbf{r}, \mathbf{V}, t)$ are the neutral and background distribution functions, respectively, and σ is the differential cross section for the collision process. The first (second) integral on the right-hand side represents scattering into (out of) the velocity v.

DEGAS 2 [1], like its predecessor, DEGAS [2], uses the Monte Carlo approach to integrating the Boltzmann equation, allowing the treatment of complex geometries, atomic physics, and wall interactions.

DEGAS 2 is written in a "macro-enhanced" version of FORTRAN via the FWEB library, providing an object oriented capability and simplifying tedious tasks, such as dynamic memory allocation and the reading and written of self-describing binary files. As a result, the code is extremely flexible and can be readily adapted to problems seemingly far removed from tokamak divertor physics, e.g., its use in simulating the diffusive evaporation of lithium in NSTX [3] and LTX [4].

DEGAS 2 has been extensively verified, as is documented in its User's Manual [5]. Experimental validation has been largely centered on the Gas Puff Imaging (GPI) technique for visualizing plasma turbulence in the tokamak edge. The validation against deuterium gas puff data from NSTX is described in the paper by B. Cao et al. [6] Analogous work with both deuterium and helium has been carried out on Alcator C-Mod. A related application of DEGAS 2 is in the interpretation of data from the Edge Neutral Density Diagnostic on NSTX [7] and NSTX-U. DEGAS 2 has been applied to many other devices, including JT-60U [8], ADITYA [9], and FRC experiments at Tri-Alpha Energy [10].

Neutral transport codes are frequently coupled to plasma simulation codes to allow a self-consistent plasma-neutral solution to be computed. Initially, DEGAS 2 was coupled to UEDGE [11]. More recently, DEGAS 2 has been coupled to the drift-kinetic XGC0 [12], and has been used in the development and testing of the simplified built-in neutral transport module in XGC1 [13]. A related project is a DEGAS 2-based synthetic GPI diagnostic for XGC1 [14].

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